Reliability, Precision and the Neuronal Code

821.12

Paul Tiesinga, Peter Thomas, Jean-Marc Fellous, Terrence Sejnowski
Sloan-Swartz Center for Theoretical Neurobiology, Computational Neurobiology Lab, Howard Hughes Medical Institute
The Salk Institute, La Jolla, CA

Introduction

Cortical neurons may use a rate code or a spike time code (for review see Shadlen & Newsome (1998)).Aspike-time code is only possible when neural discharge is reliable. The discharge of neurons driven by a constant drive is unreliable, whereas it is reliable when driven by a random fluctuating drive (Mainen & Sejnowski (1995); Cecchi et al (2000)). A neuron driven by a sinusoidal current has a reliability resonance when it produces one spike per drive cycle (Nowak et al (1997); Hunter et al (1998);Fellous et al (2001)). Here we study the behavior of the reliability in terms of attractor dynamics andbifurcations.

Methods

The dynamics of an integrate-and-fire neuron is

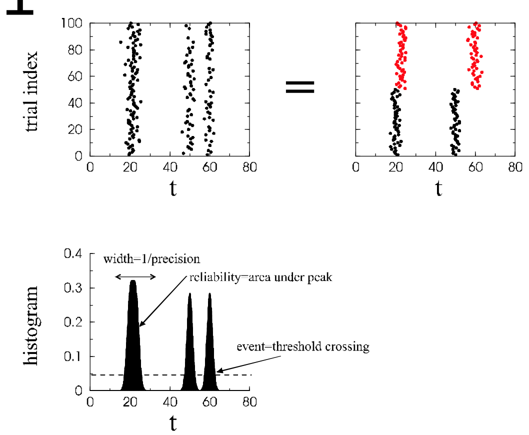
$$V' = -V + A\, f(t) + I + \xi$$

V is themembrane potential, f(t) is a fluctuating drive, A is its amplitude, I is a constant depolarizing current, ξ is a white noise current with variance D. When V reaches threshold, V=1, a spike is emitted and the voltage isresetto V=0. Dimensionless units were used, 1 voltage unit corresponds to 20 mV and 1 time unit corresponds to 10-40 ms. Experimental recordings were performedasin Fellous et al(2001).

References

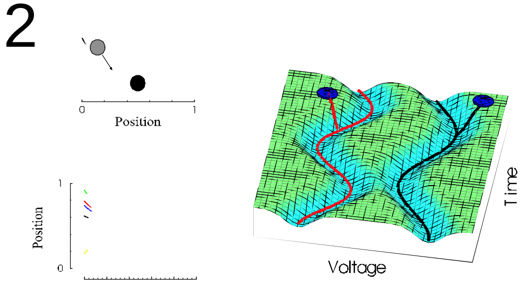
Cecchi, G., et al (2000). Proc. Natl. Acad. Sci., 97:5557-5561.
Coombes, S. and Bressloff, P. (1999). Phys. Rev. E, 60:2086-2096.
Fellous, J.-M., et al (2001) J. Neurophys., 85:1782-1787
Hunter, J., et al (1998). J. Neurophysiol., 80:1427-1438.
Mainen, Z. and Sejnowski, T. (1995). Science, 268:1503-1506.
Nowak, L., et al (1997). Cereb. Cortex, 7:487-501.
Shadlen, M. and Newsome, W. (1998). J. Neurosci., 18:3870-3896.

1



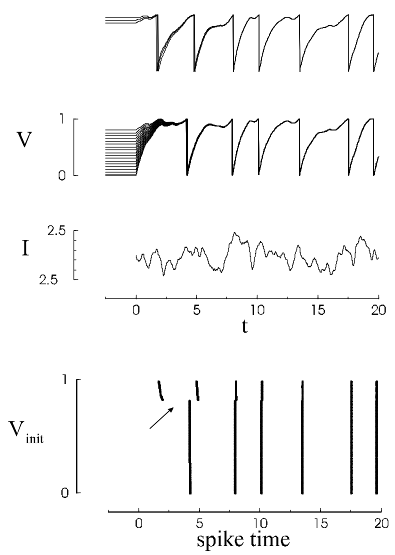
Deterministic structure of spike trains is not detected in the spike time histogram (STH) or using reliabilitymeasures based on the STH.

2



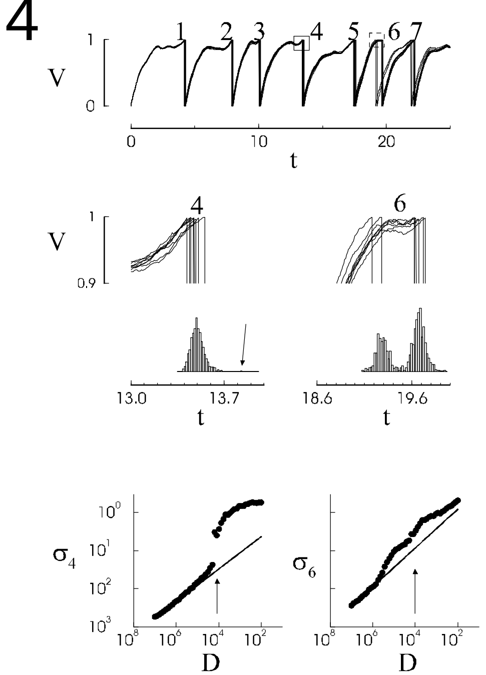
An attractor can be conceptualized as a river valley. From different initial conditions the ball rolls into the valley and follows the river flow.

3



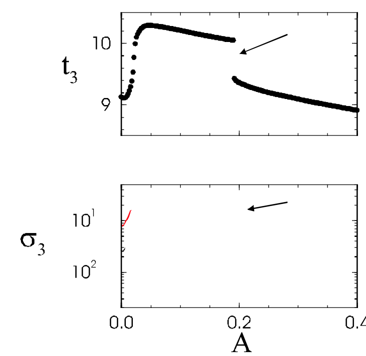
Voltage of an integrate-and-fire model neuron converges from different initial conditions to a single attractor. Reproducible spike trains are obtained.

4



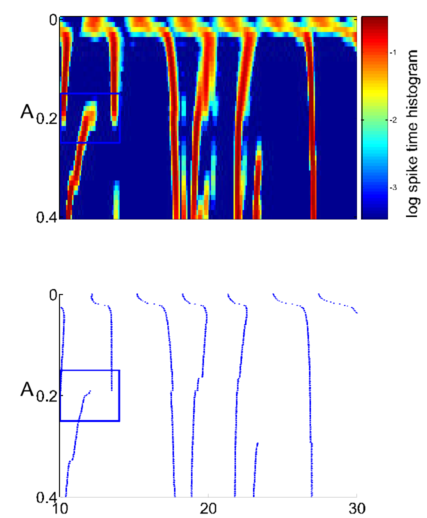
Intrinsic noise induces deviations from the attractor: (1) Distinct spike trains are obtained. (2) Reliability is reduced. (3) Spike-time jitter is not proportional to noise standard deviation.

5



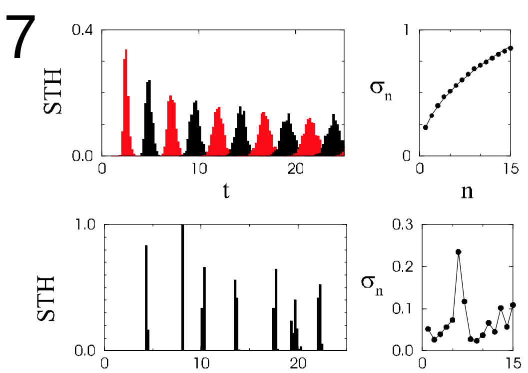
During a bifurcation spike time t_3 changes discontinuously when a parameter is varied. Close to a bifurcation point reliability is reduced and jitter σ_3 is increased.

6



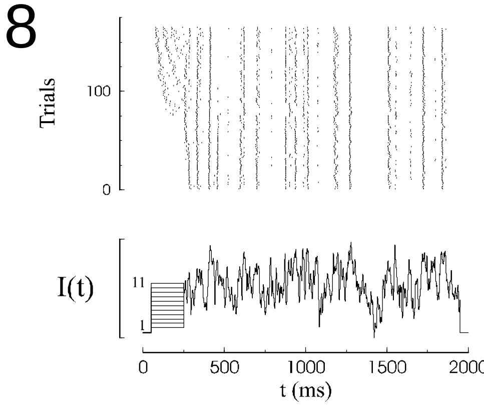
Bifurcation structure explains variation of the reliability with drive amplitudeA.

7



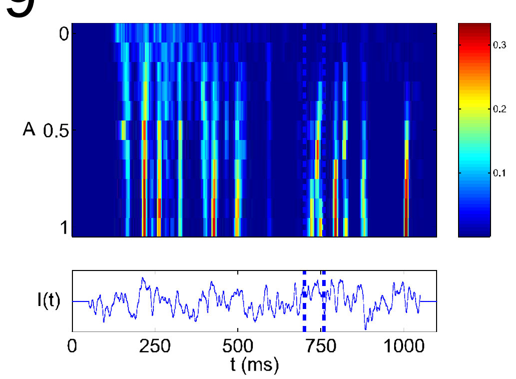
Attractor stability governs asymptotic precision.

8



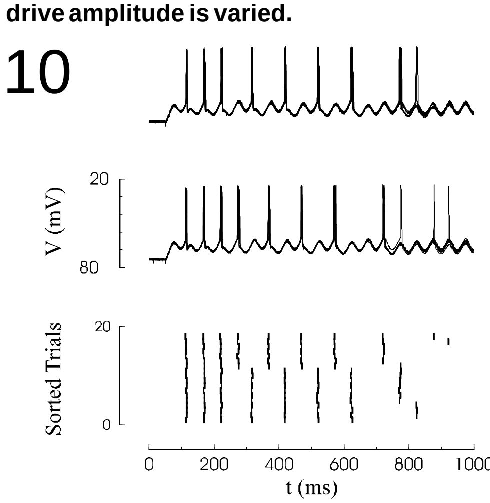
(Experiment) Spike trains recorded from cortical neurons in vitro converge from different initial conditions to similar spike trains.

9



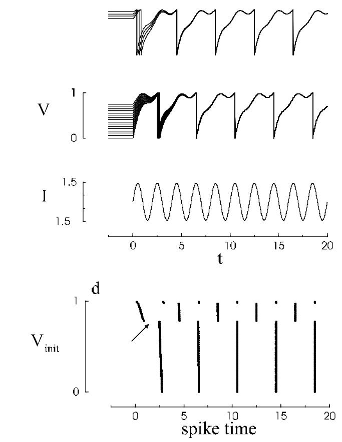
(Experiment) Bifurcations are observed in recordings from cortical neurons when the drive amplitude is varied.

10



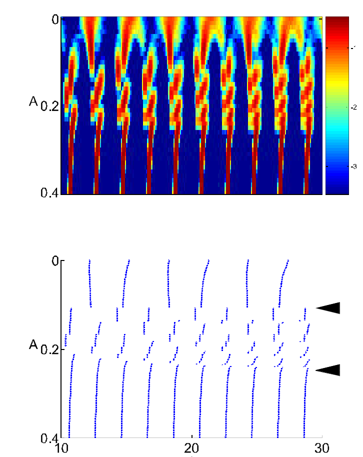
(Experiment) During 1:2 mode-locking there are two attractors.

11



Depending on initial condition one of two attractors are reached during 1:2 mode-locking.

12



Densitity of bifurcation points is non uniform for a periodically driven model neuron. A reliability resonance peak for 1:1 entrainment is obtained.

Summary

- Neuronal dynamics can be characterized in terms of attractors and bifurcations.
- Reliability is inversely proportional to the number of distinct output signals produced across trials.
- Reliability is the noise stability of attractors. A neuron confined to one attractor produces a unique output spike train.
- Reliability is reduced close to a bifurcation point.
- Periodic, random fluctuating and constant drives yield different bifurcation structures.